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Røpke, Inge

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Inge Røpke, Aalborg University

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The smart grid is often mentioned as one of the key examples of IT playing a positive role for the environment, because it is regarded as a precondition for a low carbon transition of the energy system. Households are expected to play a variety of roles in relation to the development of the smart grid. The changes are complex and involve a number of concerns and challenges for policy-making.

1 Background

The transition to a low carbon society calls for increased integration of renewable energy sources (RES) like wind power and solar energy in the energy system. This will change some of the characteristics of the energy system because the production of electricity will become more decentralised, and a larger share of energy consumption will take the form of electricity as services like heating and transportation are provided by the use of heat pumps and electric vehicles.

Since some RES are intermittent, the transition is challenged by the need to balance supply and demand. Traditionally, production has been adapted to demand, but the increased dependence on intermittent resources necessitates that demand is adjusted to supply and/or that energy can be stored to provide backup. Together demand management and the integration of many more injection points into the electricity grid call for the development of a more 'intelligent' grid that combines a power exchange highway with a data exchange highway. This is needed to enable the interaction between producers and consumers. These changes in relation to the grid are often captured by the term 'smart grid'.

There are several potential pathways for the development of a smart grid (Verbong & Geels 2010): it can be more or less centralised, be based mostly on incumbents or new actors, rely on different combinations of market constructions and more direct planning, etc. (Foxon et al. 2010). The following relates mostly to the visions that are promoted in official publications.

2 Changing roles of households

In European countries electricity was for many years a nearly invisible good, provided by a regulated monopoly at relatively low prices. Electricity savings have been promoted by various policies like labelling, but few consumers

have given much attention to the purchase of electricity. This is about to change for two reasons. First, the liberalisation of electricity markets tends to increase consumers' interest in choosing their supplier, because it becomes possible to save money or achieve other advantages when electricity traders compete to attract customers. Second, the low carbon transition can be expected to imply a general increase in energy prices, a larger share of households' energy consumption in the form of electricity, and more fluctuating electricity prices – all calling for more consumer attention to the electricity bill and the use of electricity. Simultaneously, the related development of the smart grid implies new roles for consumers as more flexible partners in the system (Nyborg & Røpke 2011).

Seen from the perspective of households, their roles in relation to the most dominant smart grid visions can be summarised under the following headings:

Energy savers

The low carbon transition is eased when households save energy. Since RES are not just free energy sources but require considerable investments and come with their own environmental problems, it should be a high priority to save energy. Smart metering, which is an integrated part of the smart grid, may encourage savings when it is implemented in a constructive way (with energy consumption displays ensuring real-time feedback, visibility, appliance-specific breakdown etc., see (Klopfert & Wallenborn 2011) and the references to Darby in the Knowledge Unit on smart metering). In some countries, electricity traders have an obligation to promote savings for their customers, but there is an obvious conflict of interest here. Also, the coalition of interests promoting the smart grid tends to give a low priority to the issue of energy savings. For them flexibility of electricity consumption is the key concern. This may imply that households do not get as much encouragement for savings as it would be desirable.

Flexibility providers

There are two reasons for asking consumers to be flexible with regard to the timing of their electricity consumption. The most obvious is the intermittent character of RES: it is best to use the electricity when the wind blows or the sun shines and thus to avoid the costs and the energy loss involved in storage of energy. The other reason relates to the capacity of the grid. The increased use of heat pumps and electric vehicles can be expected to add to the traditional peak demand, if this use is not managed in an intelligent way. Peak demand not only leads to electricity production from the most expensive marginal production units, but also puts a strain on the local grids, for instance, when many households along the same supply line decide to load their electric vehicles at the same time as most cooking takes place. To avoid expensive investments in reinforcement of the grid, the distribution service operators are interested in peak shaving and want to encourage consumers to be flexible. The two reasons for asking for flexibility may be in contradiction with each other: electricity traders are interested in selling electricity when the production price is low and when this happens in a period of peak demand, there is a conflict with the interest of the grid operators in peak shaving. This is one of the challenges for the institutional arrangements related to the smart grid.

The high-consuming activities like running the heat pump and charging the electric vehicle are obvious candidates for flexibility with regard to time. In addition, activities such as laundering and dish washing are considered to be relatively easy for consumers to displace in time.

Providers of balancing services

A particular problem related to the integration of quickly fluctuating energy sources such as wind concerns the balancing of the grid and the avoidance of sudden drops in frequency. The smart grid is intended to cope with this challenge by offering better possibilities for surveillance of the grid and for instantaneous regulation to avoid

power outages. Like other electricity users, households are expected to contribute to the balancing of the grid by offering 'regulating power' in the form of brief decoupling of appliances, such as freezers, refrigerators, washing machines, dryers, and chargers for electronic equipment – as well as heat pumps and electric vehicles. To make this possible, appliances have to be 'smart' in the sense that they can react to the management signals.

Providers of storage

The replacement of fossil fuels by RES cannot be realized without some forms of energy storage. Households are not expected to play a key role in relation to storage, but some contributions can be made, for instance, by heat pumps with storage tanks. Some energy-consuming units can store energy for later use by the unit itself, like the batteries of electric vehicles or freezers that can drop some extra minus degrees when cheap electricity is available. Moreover, some equipment can store energy that can be delivered back to the grid, as the batteries of electric vehicles are expected to be able to in the future.

Prosumers

With RES households can provide their own energy input based on solar heat, photovoltaics, wind turbines, heat pumps, and micro CHP, and in some cases, they can produce electricity to feed into the grid. While the smart grid is seen as a technical precondition for effective integration of the many small contributions, the economic arrangements related to the integration are decisive for the amount of household-based RES offered.

Investors

The transition related to transportation and heating depends on the willingness of consumers to invest in electric vehicles and in heat pumps, which is a huge challenge. In addition, most of the other household roles call for investments. Some energy savings can be achieved by behavioural changes, but larger savings usually involve the acquisition of energy-efficient appliances or investments in insulation or other housing renovations. The provision of flexibility is possible through behavioural adjustments, but smart grid scenarios usually expect consumers to prefer more automated solutions, requiring a smart meter and intelligent equipment that can be managed at a distance. In some countries consumers are expected to make the investment in the smart meter themselves, while in other countries the installation is funded by the electricity trader or the grid operator. Smart appliances, which are also a precondition for the provision of balancing services and storage, must be acquired by households. Finally, considerable investments are typically necessary if households want to become prosumers.

Active market participants

In general, smart grid scenarios are based on the idea that the low carbon transition should go hand in hand with the liberalisation of electricity markets. Households are thus expected to act as active and rational market participants. For instance, the smart grid involves the construction of various new services that households can sell, such as flexibility, balancing services and storage, and when buying electricity consumers are expected to choose between more complex offers from the traders. More actors may enter the market like, for instance, intermediaries offering to trade balancing services, and energy service companies (ESCOs) offering to invest in energy savings and take the payment in the form of these savings. In general, all of the investment activities come with their own set of actors and market constructions that households must relate to.

3 Concerns and policy challenges

As highlighted by the variety of household roles related to the smart grid, the changes are highly complex and involve a range of regulatory challenges. Some of the immediate con-

cerns related to the roles of households include (a key reference on this topic is (Klopfert & Wallenborn 2011)):

- The economics of smart meters: Are consumers going to pay, either directly or indirectly? How effective will smart meters be in encouraging savings? Are they really useful for already thrifty consumers, including low-income households?
- Privacy and security: Will the system be vulnerable to hacking? Will it be possible to protect the vast amount of person-sensitive data generated in the system?
- Standards: How can consumers be sure to invest in equipment that can be widely used when standards are not yet implemented? Do consumers run the risk of premature obsolescence? May safety issues accelerate obsolescence?
- Inequality between consumers: After liberalisation electricity traders are allowed to distinguish between different groups of household customers and offer better deals to attractive customers. This may lead to relatively higher prices for low-income than for high-income customers, who have a higher consumption and more flexibility to offer in the new markets (see e.g. on the early Swedish experience (Summerton 2004)). For instance, low-income households may not be able to afford the investments in smart appliances.
- Market transparency: Will the market for electricity foster complex price structures like the telecom market so that it becomes complicated for consumers to compare different offers?
- Ownership of data: Will consumers own their own data? Will they be able to share them with ESCOs?

In addition to these immediate concerns, more wide-ranging and intertwined issues may question the smart grid visions in more fundamental ways:

- System complexity: Is it technically and economically sensible to construct such a complex system, or can the main objectives be achieved in more simple ways? No doubt, households play an important role in relation to energy savings and the transformation towards energy use in the form of electricity. But some of the functions related to flexibility, balancing services and storage may be achieved in other ways, for instance, through services provided by industry, wholesale and retail trade, and local CHPs. Maybe flexibility is only needed in the form of moving consumption away from well-known peak periods, which may be achieved through simple price incentives and information campaigns. In addition, new developments in energy storage technologies may make the complex system obsolete relatively quickly.
- Markets vs. planning: The establishment of the smart grid will be expensive, and it is not obvious that the economic outcome will be sufficient to provide the economic incentives for various actors to make the necessary investments. A related question concerns whether incentives can emerge through market constructions or whether a return to more direct regulation will be more effective in achieving a low carbon transition of the energy system.
- Flexibility vs. savings: Often smart grid actors tend to focus more on flexibility than on energy savings. Can this focus be counterproductive in relation to the low carbon transition? The smart grid implies the involvement of firms from the IT-sector, trained in developing new consumer desires that may turn out to be energy-consuming. 'Smartness' may also encourage particular visions of homes with a high degree of automation, also in cases where manual solutions could be more environment-friendly.
- Consumer vs. citizen: The dominant smart grid visions tend to emphasize the role of households as active market participants rather than the role of engaged and responsible citizens involved in a societal transformation (Walker & Cass 2007). This focus may turn out to be counterproductive, in particular, if the economic

incentives are relatively weak. Also, the encouragement of a citizen perspective may be key to developing local solutions involving more than one household.

As these questions illustrate, there is no simple smart grid vision pointing out the uncontroversial and straightforward way ahead. Rather the smart grid forms a battleground for many interests and calls for much more discussion on how to proceed in a sustainable way.

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